The Coral Reef Early Warning System (CREWS):

marine environmental monitoring to support research and marine sanctuary management

The Effects of Combined Sea Temperature, Light, and/or Carbon Dioxide on Coral Bleaching, Settlement and/or Growth
(First Annual Combined Effects Think Tank to Support CREWS Modeling)

Caribbean Marine Research Center
Lee Stocking Island (LSI), Bahamas
January 20 - 24, 2003

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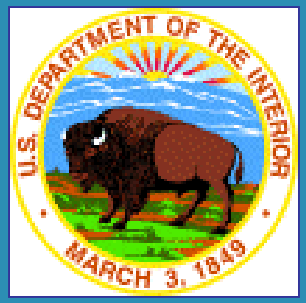
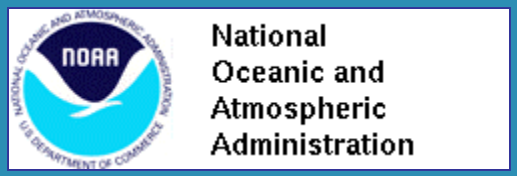
A true interagency, international collaborative effort!





- ☆ Ocean and Atmospheric Research
- ☆ National Environmental Satellite, Data, and
- ☆ Information Service
- ☆ National Undersea Research Program
- ☆ The Florida Keys National Marine Sanctuary
- ☆ National Ocean Service
- ☆ National Marine Fisheries Service
- ☆ National Data Buoy Center

Coral Reef Early Warning System (CREWS) Network

Coral Reef Watch collaboration with NESDIS (Dr. Al Strong), NOS and NMFS

A CREWS station is a suite of meteorological and oceanographic monitoring instruments, *plus* the expert system software for data screening and interpretation

Response to Coral Reef Task Force Monitoring Group's recommendation for a network of up to 18 stations at all major U.S. coral reef areas by 2006

CREWS stations provide hourly *in situ* data...

Air temperature, wind speed and direction, barometric pressure, UV-B above and below the water, PAR above and below water, sea temperature, salinity, and tide level (optional: pCO2, fluorometry, transmissometry, nutrients, acoustic monitoring, Web cam, etc.)

***...and* information synthesis products**

Surface-truth for NESDIS satellite temps, coral bleaching alerts, data quality alerts; and matching patterns as proscribed by biologists, oceanographers and the public (fish & invertebrate spawning, migration, bloom conditions, good fishing and/or diving conditions, etc.)

Linux Beowulf Cluster Supports CREWS Network

Overview: 8 node Beowulf Class cluster. 3.75GFlops benchmark. 1Gigabit networking between nodes. Switch is a D-Link Gigabit managed switch.

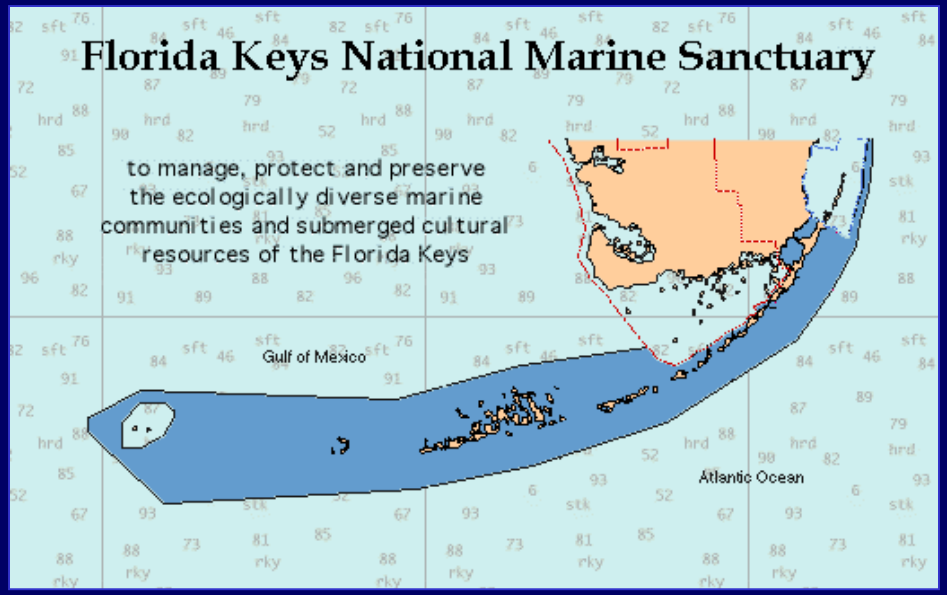
Master Node: Dual 733Mhz, 1 GB RAM, Single SCSI 160 40 GB drive, 4 SCSI 160 70 GB Drives configured in a software RAID 5. 1 Gigabit NIC and 1 10/100 NIC.

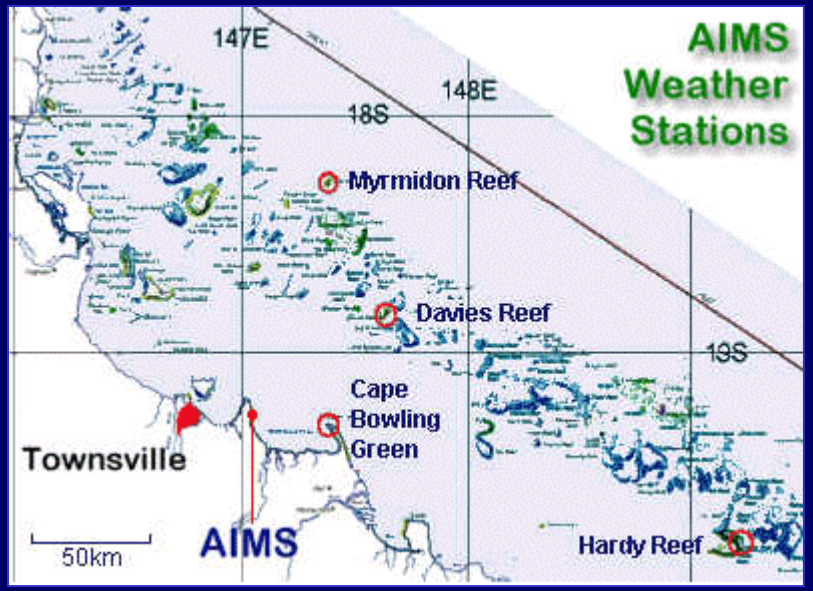
Slaves: Dual 733 MHz, 1 GB of RAM, 3 Quantum 20 GB Drives, single gigabit NIC.

Backup: Quantum DLT 40/80 GB Backup.

Extremely good security configuration.

The CREWS software is currently deployed for the Florida Keys (SEAKEYS Network), the Great Barrier Reef (AIMS Weather Station Network),





Lee Stocking Island, Bahamas, and...

Salt River Bay National Historical Park and Ecological Preserve, St. Croix; US Virgin Islands

* A new station is now being installed in John Brewers Bay, St. Thomas; USVI

* Next station after that will be near La Parguera, Puerto Rico

* The US National Park Service has expressed an interest in having additional stations near Buck Island, St. Croix; and possibly St. John

John Brewer's Bay, St. Thomas

Buck Island (on horizon) , St. Croix

Atlantic CRTF/CREWS Stations Planned

Lee Stocking Island, Bahamas (test-bed) (1)
US Virgin Islands (2)
Puerto Rico (2)

Pacific CRTF/CREWS Stations Planned

Hawaii (6)
American Samoa (2)
Guam (1)
CN Mariana Islands (2)
Johnston Atoll (1)
Howland/Baker (1)
Palmyra/Kingman (1)

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Non-CRTF CREWS Stations

SEAKEYS Stations (in Florida Keys National Marine Sanctuary)

World Bank/Global Environmental Fund *(proposed)*

Mainstreaming Adaptation to Climate Change (MACC) Project

Jamaica, Belize, and Bahamas

Targeted Research Initiative

Palau, Philippines, Heron Island, Puerto Morelos, Zanzibar

Interest expressed for non-US islands in Pacific and Indian Oceans

French Polynesia

Seychelles

Indonesia

Vietnam

Panama (Smithsonian Tropical Research Institute)

CREWS Station (test bed platform) at Rainbow Gardens Reef, Lee Stocking Island, Bahamas

Installed May, 2001

NURP/CMRC collaborative facilitates pioneering work

Site and design are for testing new instruments

Continuous (hourly) output of data

Archived & raw data will be available via Oracle server

CREWS software screening

- Coral bleaching alerts
- AVHRR surface-truth information products
- Alerts to instrument problems

Data of use to large number of researchers who visit

Data complement decades of previous studies

Data of use in upcoming research on role of UV and PAR in coral bleaching & larval settlement

Station was prototype floating design, however...

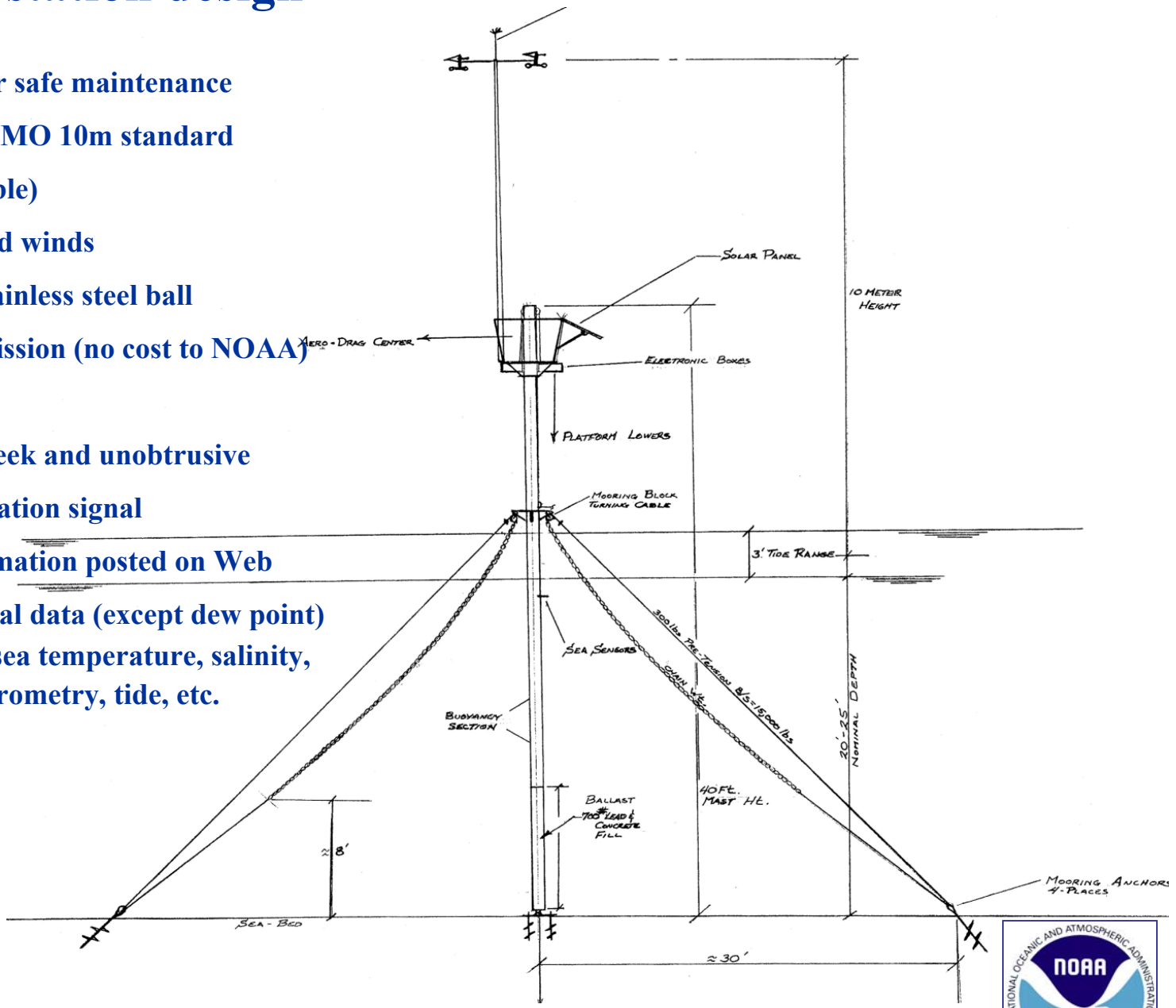
R/V Kristina

Actual example of instrument alert:

"Probable UVB-1m sensor malfunction at cmrc1 on day 287, because readings (about 2319) appear too high around 0300 to 0900 hrs GMT."

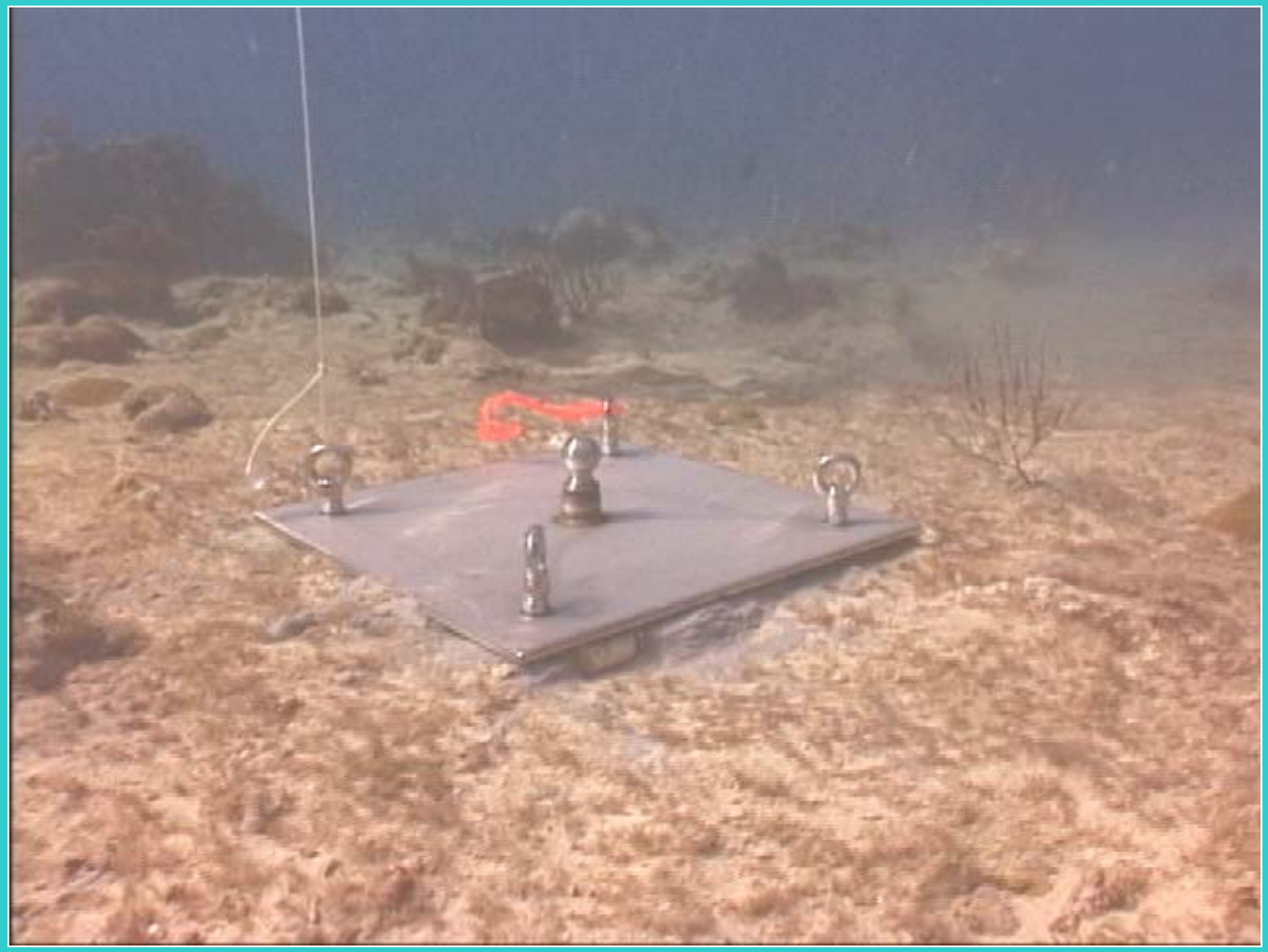
New CREWS station design

- Hoistable platforms for safe maintenance
- WindBird at NDBC/WMO 10m standard
- 20’ depth (but adjustable)
- Built for heavy seas and winds
- Has “give,” rests on stainless steel ball
- GOES satellite transmission (no cost to NOAA)
- Solar-powered
- 10” diameter spar is sleek and unobtrusive
- USCG approved navigation signal
- Hourly data and information posted on Web
- Standard meteorological data (except dew point)
- Oceanographic data: sea temperature, salinity, PAR, UV, pCO_2, fluorometry, tide, etc.

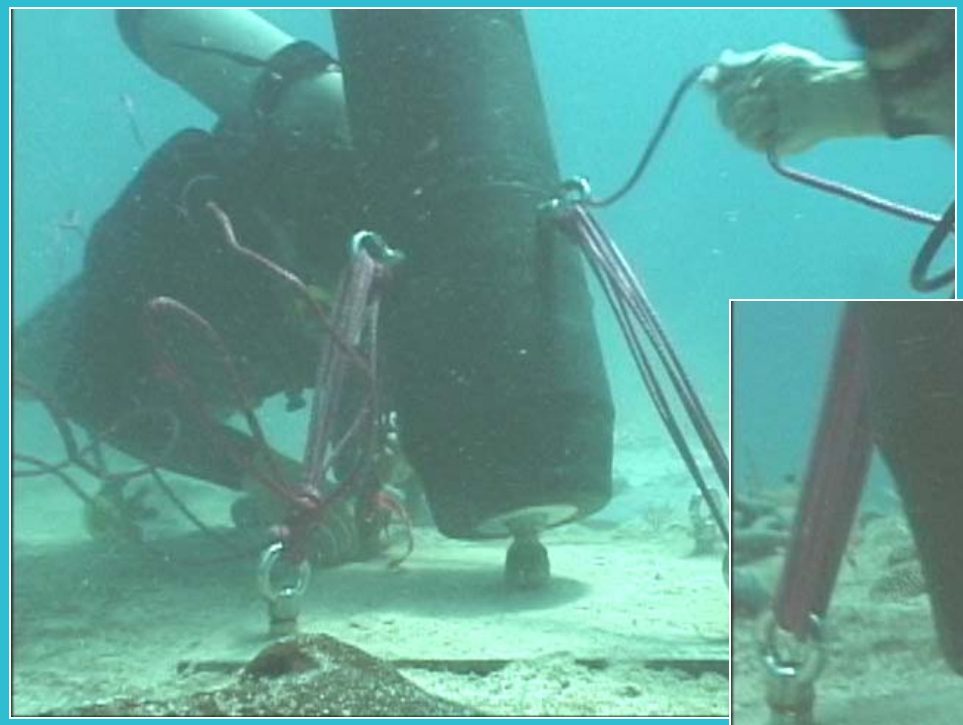


A two-foot square stainless steel plate with stainless steel ball-hitch is fastened to the bottom, and eight stainless steel mooring pins are positioned radially 30’ distant.

The target depth for all stations is about 20'. This will provide good comparison of data across locations.



The dynamic pylon is moved to the site and supported by flotation at various points before being slowly lowered to the ball and fastened down.

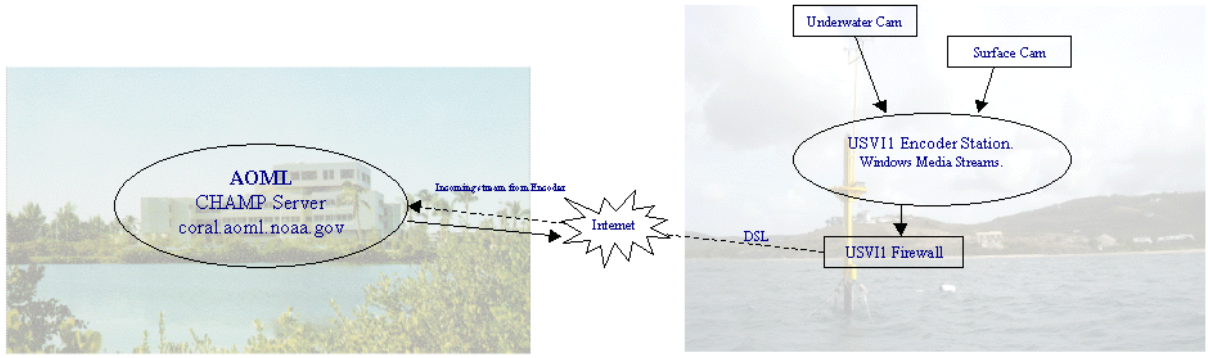


The chains and Spectra line, which act as shock absorbers, are attached to the pylon...

...then the platform is lowered and the instruments are installed.

CREWS Coral Reef Web Cam

Underwater Video Streaming Protocol from St. Croix, USVI CREWS Station



St. Croix USVI Encoding Station:

Our encoding station in St. Croix receives two live video streams. One is on-shore, looking out towards the buoy. The other stream, an underwater camera signal, is received from the buoy via microwave transmission. Both signals are fed into our onsite video encoder, which translates them into Windows Media encoded streams. Those live streams are then sent, over a Virtual Private Network (VPN) connection to AOML in Miami Florida for broadcast.

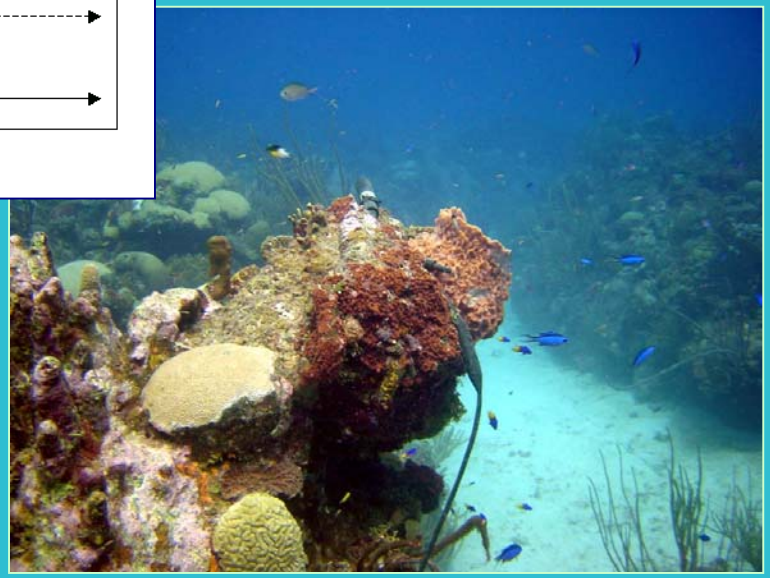
The connection to AOML is made possible because of an onsite DSL connection. The encoder itself is protected behind a firewall and the streams are encrypted before they head over to AOML. The VPN allows for the encryption and provides a direct link AOML.

Broadcast Station at AOML:

The server at AOML in Miami receives the two encoded streams from St. Croix over the VPN. It then decodes them and formats them for broadcast to the Internet. Those broadcasts are linked to from our Coral server for all users of the Internet.

Legend:
VPN connection between USVI1 and AOML Netscreen firewalls. ----------→

Outgoing Real Media and/or Windows Media Broadcasts ——→



The CREWS Coral Reef Web Camera is currently broadcasting from a depth of about 45' at the St. Croix CREWS station.

"As conservationists we can't afford to sit on data for a year. We can't afford to sit on it for a week."

J. Michael Fay
(conservationist and adventurer)

CREWS was designed to give rapid feedback information (not just data) on the marine environment to support researchers, and sanctuary or MPA managers.

The CREWS software has three principal components:

* Raw data parser--makes columnar data report from raw data stream
* Environmental Information Synthesizer for Expert Systems (EISES)
* Expert system (type of Knowledge Based System) for coral bleaching

EISES/CREWS is unique for marine ecosystem monitoring, and is one of a breed of new Artificial Intelligence techniques called ***Environmental Decision Support Systems***

CREWS derives its input from data files retrieved in near real-time from remote stations. Here is an example from Sombrero Key, near Marathon, in the Florida Keys:

Sombrero Key SEAKEYS/C-MAN Report--Meteorology (NOAA/NDBC)

Date	Time	Baro	WD	WSp	WGu	DewP	AirT	SeaTemp
02/24/99	0900	1017	8	16.3	18.2	13.7	17.0	23.4
02/24/99	0800	1016	340	13.3	14.1	13.4	18.1	23.3
02/24/99	0700	1017	329	11.7	13.1	13.7	18.3	23.3
02/24/99	0600	1017	334	11.3	12.0	13.3	18.3	23.3
02/24/99	0500	1018	341	9.5	10.7	13.3	18.3	22.8
02/24/99	0400	1018	337	10.2	10.9	13.0	18.1	23.0
02/24/99	0300	1018	343	13.8	14.8	12.9	18.1	23.1
02/24/99	0200	1018	346	13.7	14.7	13.1	18.1	23.3
02/24/99	0100	1018	336	12.1	13.4	12.7	18.1	23.5
02/24/99	0000	1017	337	14.1	16.1	12.5	18.0	23.6

Data Grouping in CREWS

Subjective Data Ranges:

ul	unbelievably low	av	average
dl	drastically low	sh	somewhat high
vl	very low	hi	high
lo	low	vh	very high
sl	somewhat low	dh	drastically high
		uh	unbelievably high

Subjective Periods of the Day:

Abbrev	Period	GMT Time	Local (5 hours)	Local (4 hours)
(Basic Periods)				
midn	midnight	0300 - 0600	2200 - 0100	2300 - 0200
pdaw	pre-dawn	0600 - 0900	0100 - 0400	0200 - 0500
dawn	dawn	0900 - 1200	0400 - 0700	0500 - 0700
morn	morning	1200 - 1500	0700 - 1000	0800 - 1100
midd	mid-day	1500 - 1800	1000 - 1300	1100 - 1400
psun	pre-sunset	1800 - 2100	1300 - 1600	1400 - 1700
suns	sunset	2100 - 2400	1600 - 1900	1700 - 2000
even	evening	0000 - 0300	1900 - 2200	2000 - 2300
(Large Groupings)				
all	all-day	0300 - 0300	2200 - 2200	2300 - 2300
dayl	daylight-hours	0900 - 2400	0400 - 1900	0500 - 2000
nite	night-hours	0000 - 0900	1900 - 0400	2000 - 0500
dayb	dawn-morning	0900 - 1500	0400 - 1000	0500 - 1100
aftn	afternoon	1800 - 2400	1300 - 1900	1400 - 2000

Representation of “facts” within CREWS:

(lonf1 barom 1001 low midnight of day 289)
(lonf1 barom 1003 low pre-dawn of day 289)
(lonf1 barom 1004 low dawn of day 289)
(lonf1 barom 1006 somewhat-low afternoon of day 289)
(lonf1 fluoro 0.008 drastic-low pre-dawn of day 295)
(lonf1 fluoro 0.031 somewhat-low sunset of day 293)
(lonf1 salin1m 31.4 very-low afternoon of day 291)
(lonf1 salin1m 31.4 very-low midnight of day 292)
(lonf1 salin1m 31.5 very-low mid-day of day 291)
(lonf1 salin1m 31.4 very-low afternoon of day 291)
(lonf1 salin1m 31.4 very-low midnight of day 292)
(lonf1 salin1m 31.5 very-low mid-day of day 291)
(lonf1 sea1m 29.0 somewhat-high afternoon of day 293)
(lonf1 sea1m 29.2 somewhat-high evening of day 294)
(lonf1 sea1m 29.2 somewhat-high sunset of day 294)

Decision Table--Theoretical Harmful Algal Bloom ES

Rule Hi Fluor + Low Winds + Low Tide — Season: Summer — JD: 172 to 264

	ul	dl	vl	lo	sl	av	sh	hi	vh	dh	uh
IF											
Fluoro									all (24) dayl (15), nite (9), dayb (6), aft (6), or basic (3)*	all (48) dayl (30), nite (18), dayb (12), aft (12), or basic (6)*	
Wind Speed		all (24) dayl (15), dayb (6), aft (6), or basic (6)**	all (24) dayl (15), dayb (6), aft (6), or basic (6)**								
Tide		all (24) dayl (15), dayb (6), aft (6), or basic (6)**	all (24) dayl (15), dayb (6), aft (6), or basic (6)**								

THEN

Conditions may be conducive to a harmful algal bloom.

Add up all the points and output in "alert" which shows totals for each parameter, as well as combined total. Total points would act as environmental index of HAB probability.

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* One of the eight basic three-hour periods.

** One of the eight basic three-hour periods, except any during night time.

“Despite the available experimental evidence that zooxanthellae and many other biological systems are effected by oxygen toxicity, Goreau and Hayes (1994) discounted the role of UV radiation as a cause and oxygen toxicity as an underlying mechanism for bleaching… Certainly, elevated temperatures have been shown to be the principal environmental cause of bleaching, and UV radiation can also cause bleaching in corals...”

Lesser, M. 1996. Elevated temperatures and ultraviolet radiation cause oxidative stress and inhibit photosynthesis in symbiotic dinoflagellates. Limnol. Oceanogr. 41(2): 271-283.

Maximum projected increases in UV in tropics may include any or all of the following:

1. Most dramatic effects will be limited to upper 1 m of water column.

2. Even small increases in UVB will likely have sublethal effect on photosynthesis, respiration, calcification, growth, and planula release where UVB increases occur.

3. Interactive effects, especially with increases in water temperature, will be greater than the sum of the independent effect.

4. We will be unable to detect these changes by techniques and monitoring programs *currently* in use.

Major needs for predicting future changes related to UV radiation are:

1. Good estimates of increased spectral irradiance, and,

2. Good experiments documenting the effects of increased spectral irradiance on survival and reproduction.

***From*: Shick, J.M., Lesser, M.P. & Jokiel, P.J. 1996. Effects of ultraviolet radiation on corals and other coral reef organisms. Global Change Biology 2: 527-545.**

Coral Bleaching Models Available to CREWS

- **Very high sea temperature only.**
- **Very high sea temperature, and very low winds during midday.**
- **Very high sea temperature, very low winds, and very low tide during midday.**
- **Very high sea temperature, high illumination (through PAR or UV-B), low winds, and high water clarity (through transmissometry) during midday.**
- **Very high sea temperature, high illumination, high water clarity and very low tide during midday.**
- **Very high sea temperature, high illumination, high water clarity, very low tide and very low winds during midday.**
- **Very low salinity or very high salinity.**
- **High or low salinity, high illumination, high water clarity, very low tide and very low winds during midday.**
- **Very high or very low salinity, high illumination, high water clarity, very low tide and very low winds during midday.**

~~~~ Coral Bleaching Alert for Sombrero Key, 08/12/1998 ~~~~

Rule-T4 (9)
Conditions possibly favorable for bleaching night-hours on 08/12/1998,
because FIO sea temperature was very high (about 31.2).

Rule-TWT1 (48)
Conditions favorable for bleaching on 08/11/1998, because
FIO sea temperature was very high (about 31.2) during mid-day,
wind speed was very low (about 5.9), during mid-day,
and tide was very low (about -4.40) during mid-day.

Rule-T5 (6)
Conditions possibly favorable for bleaching afternoon on 08/11/1998,
because FIO sea temperature was very high (about 31.5).

Rule-T8 (3)
Conditions possibly favorable for bleaching evening on 08/11/1998,
because FIO sea temperature was very high (about 31.0).

Rule-T8 (3)
Conditions possibly favorable for bleaching morning on 08/11/1998,
because FIO sea temperature was very high (about 31.0).

Rule-T5 (6)
Conditions possibly favorable for bleaching afternoon on 08/10/1998,
because FIO sea temperature was very high (about 31.3).

... [etc.] ...

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High temperature points:	**138**
High temperature, low wind points:	**0**
High temperature, low wind, low tide points:	**48**
Number of rules triggered:	**18**
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~~~~ Sombrero Key Conch Larval Drift Alert for 08/25/2000 ~~~~

Rule: Dawn/morning (6 points)
Winds were approximately easterly at 91 degrees,
during dawn/morning hours on day 08/24/2000.

Rule: Dawn/morning (6 points)
Winds were approximately easterly at 90 degrees,
during dawn/morning hours on day 08/22/2000.

Rule: Afternoon (6 points)
Winds were approximately easterly at 89 degrees,
during dawn/morning hours on day 08/21/2000.

Rule: Afternoon (6 points)
Winds were approximately easterly at 95 degrees,
during dawn/morning hours on day 08/20/2000.

Rule: Dawn/morning (6 points)
Winds were approximately easterly at 85 degrees,
during dawn/morning hours on day 08/19/2000.

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Easterly wind count points: 39
Number of rules triggered: 5

Multi-station or Synoptic Rules (Hurricane Irene, “Very Low” Salinity)

Rule-1 (low salinity alert, SMKF1 >= 1 day after LONF1)

Long Key salinity about 31.9 (very-low), Day 290 dawn-morning
Sombrero salinity about 34.0 (very-low), Day 291 mid-day

Bloom detection production rule at Long Key (prototype):

```
Rule Flu-Wind-PAR-1 (high fluoro, low wind, high PAR)
Day 146
~~~~~~~~~~~~~~~~~~~
Fluorometry was about 0.082 (very-high mid-day)
Wind Speed was about 4.4 (low mid-day)
Wind Direction was from NE-ENE direction (mid-day)
PAR was about  969 (high mid-day)
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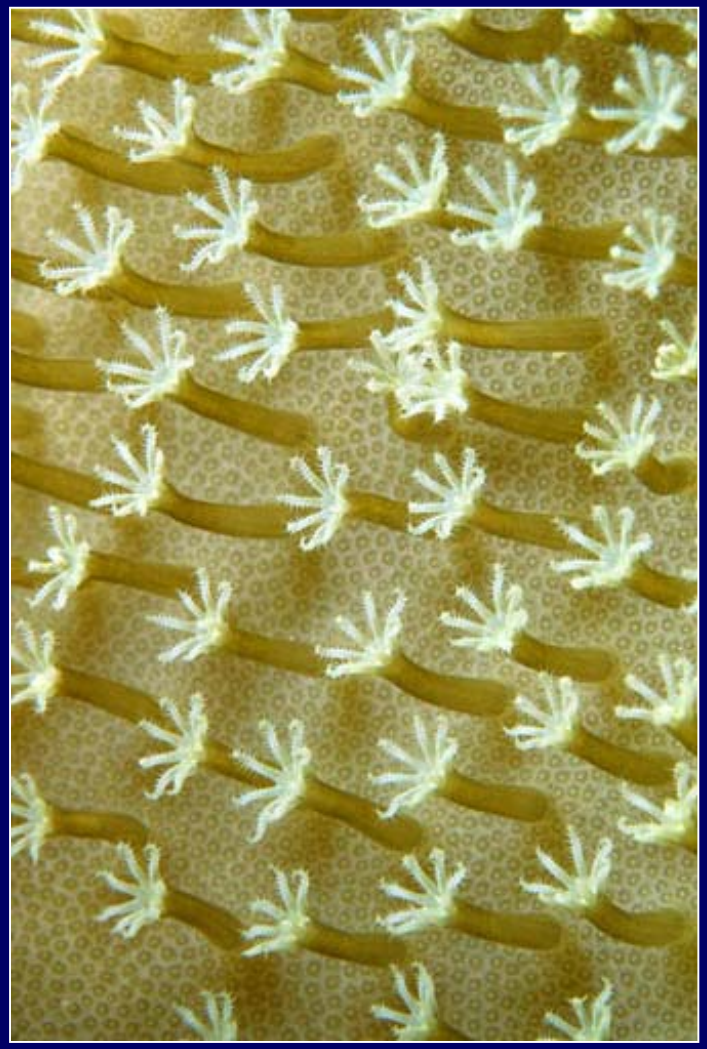
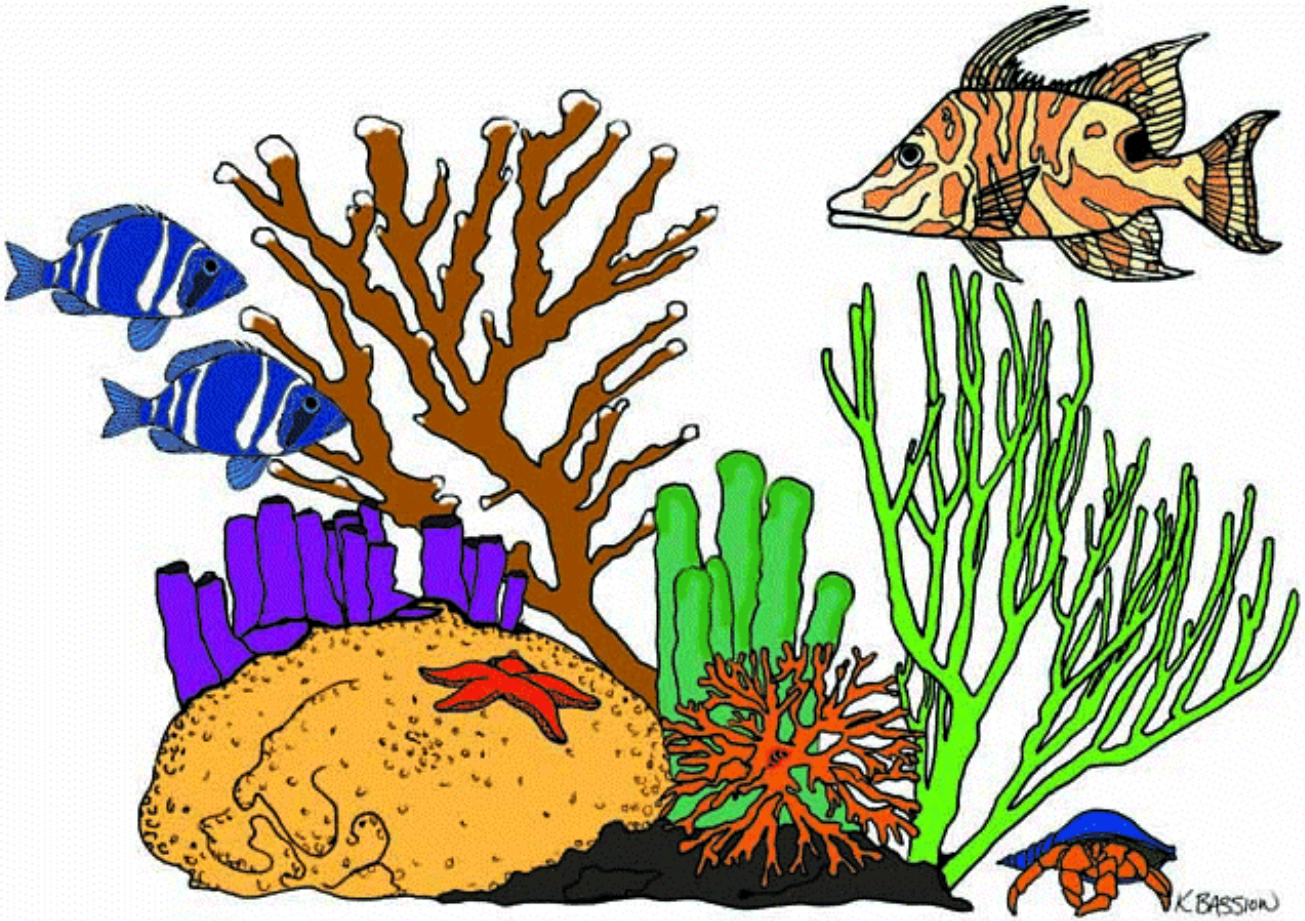
What does all this mean?

- **Expert systems can automatically do a lot of work the experts can.**
- **CREWS can synthesize *information* from data.**
- **CREWS can work with *in situ* instruments, or satellite instruments, or both.**
- **CREWS can send alerts when prescribed conditions are met.**





Coral Health And Monitoring Program